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Heavy Metals and Microbial Activity in Alluvial Soils Affected by Different Land-Uses

Abo Shelbaya, M. M.[1]; M. M. Abd El-Azeim[1*]; A. M. Menesi[1] and M. M. Abd El-Mageed[2]

[1] Soil Science Department, Fac. of Agric., Minia University, Egypt.
[2] Crops department, Fac. of Agric., Minia University, Egypt.

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ABSTRACT

Soils must receive maximum protection to assure sustainable agriculture and quality food production. Heavy metals tend to accumulate in the soil rather than decompose and at a certain limit of their content, toxic consequences for living organisms occur. This research was conducted to survey the contamination status of Cd, Cr, Ni, and Pb and microbial activity in soils affected by long-term sugarcane monoculture in Upper Egypt. The rise of diacetate fluorescein hydrolysis (FDA) ranged from 86.25 to 201.25 mg kg^{-1} soil·h^{-1} in sugarcane monoculture fields, while the increase under crop rotation fields showed higher and significant values ranged from 207.25 to 266.67 mg kg^{-1} soil·h^{-1}. In this study, generally soil microbial biomass and enzymatic activity was usually and significantly higher under crop rotation than sugarcane monoculture. The highest potential ecological risks were found in soils under long-term irrigated sugarcane monoculture, while being moderate for crop rotation. Under both sugarcane monoculture and crop rotation farming systems, cadmium Cd was observed to be the urgency pollutant with the highest degree of contamination even though Cd had the lowest average concentration (Cd 27.03 mg kg^{-1}) in sugarcane monoculture fields, and Cd (10.46 mg kg^{-1}) in crop rotation. In view of the impacts of these potentially toxic elements of cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb), on the ecological system and public health, the introduction of new management practices in sugarcane monoculture fields are essential to protect the environment and to achieve future sustainability in sugarcane production in Upper Egypt.

Keywords: Sugarcane Monoculture, Ecological hazard, Diacetate fluorescein.

INTRODUCTION

Recently there has been growing evidence of decreased soil productivity as a result of long-term irrigated sugarcane (*Saccharum officinarum* L.) monoculture joint with the intensification of irrigation and fertilization systems (Umrit *et al*., 2014; Ouda, 2020; Wu *et al*., 2020). Sugarcane monoculture is known to affect soil properties by continued additions of pesticides and organic and inorganic fertilizers leading to conditions that might affect soil physicochemical parameters and promotes solubility, bioavailability and mobility of heavy metals (da Silva *et al*., 2016; Wang *et al*., 2018; Wang *et al*., 2020). As a result, a series of soil quality degradation problems have appeared in irrigated sugarcane monoculture areas in Egypt, including heavy metal soil contamination and degradation of soil biological properties which is a major limiting factor affecting soil health. In addition to damaging the soil health, structure, function, this heavy metal pollution directly affects human health and plant growth development (Lodhi *et al*., 2021; Qin *et al*., 2021).

Heavy metal soil contents in an agricultural ecosystem environment are relatively undegradable and are difficult to be removed through natural processes (da Silva *et al*., 2016; Wang *et al*., 2020; Jadoon *et al*., 2021). Therefore, the monitoring and assessment of the environmental quality of soils plays a significant role in restoring damaged ecosystems, protecting soil environmental quality, and developing a scientific basis for sustainable intensive agricultural systems (Lodhi *et al*., 2021; Qin *et al*., 2021). Heavy metals cause a great threat to the environment and public health if the levels go beyond admissible limits (Haddad *et al*., 2019; Tudi *et al*., 2021). Cadmium, Chromium, Lead and Nickel are cumulative toxic heavy metals with features of high mobility and chemical activity, so availability for uptake by plants threaten safety of agricultural products and human health (Jadoon *et al*., 2021).

In Egypt, sources of the agricultural soil contamination involve the utilization of contaminated agrochemicals, irrigation with saline and polluted groundwater, the reuse of drainage water, the recycling of wastewater, the polluted air, and the inappropriate disposing of solid wastes (Abd El-Azeim *et al*., 2016). These various sources pose a great threat to the sustainable agricultural ecosystems and soil health (Abd El-Azeim *et al*., 2016; Cheruben *et al*., 2016; Haddad *et al*., 2019). Heavy metals have been identified to alter soil physical and chemical properties that affect the biological population, diversity, fertility, and soil health (Sahu and basti 2021). Excessive tilth, irrigation, fertilization and management practices that diminish organic matter and nutrients have also been recognised as primary factors contributing to the yield decline in sugarcane monoculture systems (Umrit *et al*., 2014; da Silva *et al*., 2016; Wang *et al*., 2018; Wang *et al*., 2020). With each other, these agricultural practices induce dilapidation of the soil chemical, physical and biological properties as evidenced by increased accumulation of heavy metals, decreased levels of SOM, lower cation exchange capacity and pH, increased bulk density, less microbial biomass activity and a build-up of detrimental soil microorganisms (Garside *et al*. 1997b; Solanki *et al*., 2020; Wang *et al*., 2020).

In recent years, numerous soil and plant heavy metal contamination valuation methods have been developed, involving the index method. At present, the Hakanson index method is the most scientific and comprehensive approach to

[*] Corresponding author.
E-mail address: mohyeldeen.elatar@mu.edu.eg
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assess heavy metal contamination in soils (Wang *et al*., 2013). Other indices like geo-accumulation index (I*geo*), pollution index (PI), contamination index (CI), enhancement factor (EF), have also been broadly used to determine the soil metal contamination (Diop *et al.* 2015; Sahu and basti 2021). Transformation factor (TF) is one of the main components which calculates the differences in bio-availability of heavy metals to plants from the soil rhizosphere, and to identify the efficacy of the plant to cumulate the given metal. Heavy metals have the capability to translocate from soil to the plant parts and can be determined by the transfer factor (TF) (Kumar *et al*., 2020).

Soil ecological problems caused by heavy metals contamination under irrigated sugarcane monoculture and agricultural expansion have attracted a great deal of research attention in the tropical areas yet not under arid conditions. Previous researches have inspected that soil microbial diversity, soil enzymatic activity, crop yield could be affected by different soil management practices, and all these soil crop quality properties were improved under intercropping systems than sugarcane monoculture (Yang *et al.* 2013; Wang *et al.* 2014; Solanki *et al*., 2020). Soil microbiological and enzymatic characteristics have been used as soil health indicators, since they are sensitive to changes in agricultural management practices (Souza *et al*., 2012). Microbial biomass carbon (C_{mic}), and N (N_{mic}), basal respiration (BR), urease (UA) and β-glucosidase (GA) activities, the potentially mineralizable N (PMN) and the hydrolysis of fluorescein diacetate (FDA) are the main soil biological indicators used in the study of soil quality (Vieira *et al*., 2020; Khadem *et al*., 2021).

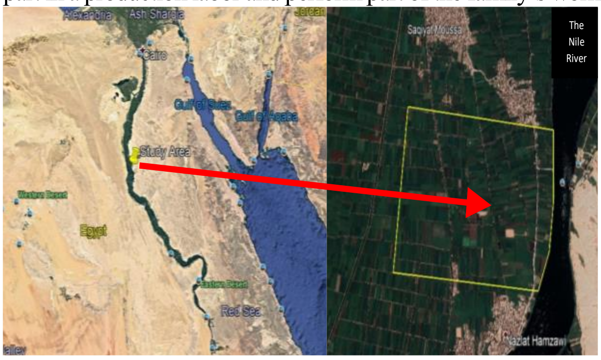
FDA hydrolysis enzyme activity is one of the most sensitive soil biological bioindicators, in relation to soil quality and fertility as it is proposed the best indicator of the microbiological redox-systems and adequate parameter of microbial oxidative activities in assessment of soil quality and health therefore, studying the role of FDA different methodologies is important (Vieira *et al*., 2020; Khadem *et al*., 2021). The hydrolysis of fluorescein diacetate (FDA) is a measure of the soil overall microbial activity and reflects the activity of numerous hydrolytic enzymes including esterase, protease and lipase. Thus, FDA hydrolysis enzyme in the soil is very important as it may give indications of the soil potential to support biochemical processes, which are essential for maintaining soil fertility as well as soil quality (Khadem *et al*., 2021). Results introduced by Solanki *et al*., (2020), clinched some interesting results of intercropping agricultural systems that certainly enhanced the soil microbial variety and this type of strategy could help to foster multiple crops to enhance the economic growth of the country by sustainable sugarcane monoculture production.

Long term sugarcane monoculture for sugar production in Egypt uses repeatedly intensive surface irrigation and ample amounts of agrochemicals and the effect of these agricultural practices on the agroecosystem has not been determined. Yet, little is recognised concerning the impacts of sugarcane farming on soil quality under arid conditions. Such data is of specific importance to both sugarcane small farmers and to environmental protection decision-makers responsible for sustainable management of the arable soils and water resources of the Governorate. This information would be invaluable unless comparisons made between sugarcane monoculture system and both uncultivated soils (control) and the other major crop rotation agricultural system in the Governorate. In this study the effects of long-term irrigated sugarcane monoculture on soil heavy metals content and microbial biomass activity were investigated under sugarcane monoculture compared to crop rotation irrigated with groundwater.

MATERIALS AND METHODS

1- Study area and data collections

The study area is located in Upper Egypt covering an area of approximately 400 hectares of sugarcane monoculture and crop rotation systems within the narrow Nile Valley and between the Western and the Eastern deserts, in Abu-Qurqas district, El-Minia Governorate, Egypt. This area was used to represent the sugarcane farming areas in the main Egyptian sugar belt of five Governorates of El-Minia, Sohag, Luxor, Qena and Aswan lies in Upper Egypt. In El-Minia Governorate (latitude 28.05º, longitude 30.44º and elevation 40.00 m), a part of the fertile alluvial soils around the Nile Valley in Abu-Qurqas district lies between three villages (Saqiet Mousa village, Nazlet Makeen village and Nazlet Hamzawy village) was carefully chosen as it is one of the major sugarcane monoculture areas besides its proximity to New Abu-Qurqas Sugar Factories (Map 1). Abu-Qurqas sugarcane farming belt was also chosen because it has many small farmers who have implemented monoculture practices of sugarcane for long periods. Sugarcane monoculture activity in the area under study is considered a type of subsistence farming or activities to live with limited agricultural natural resources of arable soil and water. All the family members take part in a production labor and perform part of the family's work.



Map 1. Study area map and area close-up.

The study area is considered as an arid zone and is covered by a desert very hot and dry climate in summer and cold in winter. The typical climatical data over the last 5 years was gathered from a national meteorological station close to the study area showed that the extreme temperature is approximately 36.68 ºC during the summer months, while the minimum temperature is about 6.08 ºC during winter season and the humidity fluctuated from 55 to 87% during the year. The temperature sometimes reaches zero at night during January and February, as the cultivated plants suffer from the risk of frost. The annual precipitation is around 2.0 mm year and only during the last year 2020, annual rainfall exceeded 53 mm indicating that change might come due to the phenomenon of climate change.

In the area under investigation, data were collected by interviewing small sugarcane farmers using an amassed administrated questionnaire. The administrated questionnaire covered irrigation water resources, irrigation methods, fertilization management, sugarcane varieties, mechanized services and tillage, postharvest treatments, sugarcane farming experience, land ownership and acreage, farmers' own farming practices, and finally production costs and farmers perspectives of soil quality. In addition, meeting the extension officers of the agricultural associations situated in the investigated area were approached to acquire information about monocultural areas and management practices in different farms. Both interview strategies were verified and found to harvest similar conclusions.

Summary of personal interviews and field visits for data collection.

In the area under investigation, before accomplishment of the literature review data were collected by interviewing small sugarcane farmers and the extension officers of the agricultural associations situated in the research area to acquire information about monocultural areas and management practices in different farms using an amassed administrated questionnaire. Both interview approaches were verified and found to harvest similar conclusions. Acquired beneficial management practices information in general were as following:

Sugarcane and crop rotation agricultural practices implemented.

The experimental fields primarily exposed to soil tillage with a disc harrow at 0.30 m depth for sugarcane implantation, which denotes the traditional management for sugarcane replanting accomplished each 5–6 years. At each gathering, the field was burned, manually cut and then mechanically collected using conventional loaders and then stems were placed on tipper tractors and then transported to the New Abo-Qurqas Sugar Factories. Information of crop plantation history, involving cultivars, rotations, and artificial fertilizers and organic manure usage, from 2017, 2018 and 2019 was recorded for all of the soil sampling sites.

The main types of fertilizers used are nitrogen in the form of ammonium nitrate (33.5% N), urea (46.5% N), ammonium sulphate (20.6% N), calcium nitrate (15.5% N); phosphorus in the form of single superphosphate (15% P_2O_5), concentrated superphosphate (37% P_2O_5); potassium in the form of potassium sulphate (48 to 50% K_2O), potassium chloride (50 to 60% K_2O). Some imported and local mixed and compound fertilizers comprising macronutrients such as N, P, K and micronutrients such as Cu, Mn, Zn, Fe in different formulas for either soil or foliar application were also used. The micronutrients may be in either artificial or chelate forms. In sugarcane monoculture farming systems, artificial fertilizers, specifically nitrogen, phosphorus and potassium are being applied to an increasing extent. In Egypt, small-farmers of sugarcane or crop rotation systems fertilize mainly based on their own experience and purchasing power. Farmers invest large amounts of NPK fertilizers into sugarcane agricultural fields to ensure high yield as they believe that high input is a high output. Intensive use of organic and inorganic fertilizers and pesticides characterizes these farming systems along with the use of gypsum for pre-cultivation land preparation.

The survey data showed that yearly application rates of NPK in Abu-Qurqas district sugarcane farming systems ranged from 700 to 850, 1250 to 1500 and 550 to 700 kg ha^{-1}, respectively. And always 20% of the N and K fertilizers were used as base fertilizers, and 80% of them were applied topdressing through the season. All P fertilizers were always applied as basal fertilizers. On the other hand, different amounts of total nitrogen (N), phosphorus (P) and potassium (K) fertilizers were applied to the investigated crop rotation sites depending on the crop type, which ranged from 250 to 450 kg N ha^{-1}, 180 t0 360 kg P_2O_5 and 270 to 500 kg K_2O ha^{-1}. The highest values of NPK were used in the case of potato cultivation, and the lowest in the case of wheat. Sugarcane monoculture or crop rotation farming systems in this area is based on the practice of 100% surface irrigation system using lift tube-wells groundwater. The studied area has been irrigated by surface irrigation using groundwater at least fifty years ago in both sugarcane and crop rotation systems.

The crop rotation farming systems are mainly maize/berseem/wheat rotation and vegetable/medicinal plants /berseem, while the management pattern of the latter includes sometimes greenhouse or open-air planting for vegetables. Generally, investigated sugarcane and crop rotation farms are irrigated from groundwater extracted from several scattered pumping wells belong to the Nile Quaternary groundwater aquifer. In most sugarcane farms, the sugarcane variety was Giza Taiwan (G.T) 54-9, and after insecticides and fungicides application, other field management practices were the same as usual used in the local sugarcane farming or crop rotation systems production. Traditionally, sugarcane in Egypt is harvested manually and during harvesting sugarcane crop leaves behind massive quantities of trash which have to be managed with state-of-the-art methods. By contrast, farmers to get rid of trash blanket, pre- or post-harvest burning is a common practice due to labour shortages. In general, sugarcane production in this area is mostly based on accrued experience and the production method is relatively traditional and stable. There are no other noteworthy anthropological activities other than agricultural activities in this area that affect soil and aquatic environmental deterioration and pollution.

2- Soil and plant sampling

The soil sampling sites were selected based on a grid of 2 km × 2 km in accordance with the layout of the functional areas of sugarcane monoculture or crop rotation and irrigation system implemented. To evaluate effects of sugarcane monoculture and crop rotation on soil quality properties, triplicates of thirty (30) composite top soil samples (0-30 cm around plant roots rhizosphere) were randomly collected twice in summer (July) and winter (January), 2017 and 2018. The coordinates and ground elevation for soil sampling sites were recorded using a Global Positioning System (Garmin GPS v) prior to establishment of the experiment. Soil samples were collected from 15 sampling sites of typical sugarcane monoculture and another 15 sampling sites of typical crop rotation farms of alluvial soils located alongside the Nile riverbank. In parallel, samples of undisturbed and uncultivated soil in the original landform as a reference soil were taken as a control. Sampling sites were located along a connexion route, each 100 m from the next and 20 m from borders of roads, drains and irrigation wells. At each sampling site, sugarcane plant (roots and stems) and both wheat (in winter) and maize (in summer) plant samples were collected, combined and then crop samples were halved by applying the quartering method as one representative sample (approximately 0.5 kg each) and kept in cloth bags, then packed in a cooler box with ice at 4 °C before transportation until analysis. The composite soil samples were thoroughly mixed and unwanted materials present were removed and then 500 grams of soil was obtained for the analysis of selected soil physicochemical properties in accordance with Page *et al*., (1982); Avery and Bascomb, (1982). Physicochemical properties of the soil samples collected from sugarcane or crop rotation farming systems are shown in Table 1.

3- Determination of soil total microbial activity.

The spread of fluorescent color development during soil incubation with buffer is a symbolic of the enzymatic activity of the microbiological biomass in the soil sample. The fluorescein diacetate (FDA, mg kg^{-1} soil h^{-1}) activity was then measured calorimetrically at 490nm wavelength and equated to a standard curve to evaluate the relative microbiological activity in soil samples using FDA (2 mg ml^{-1} acetone) as a substratum in accordance with Patle *et al.* (2018). The Hydrolysis of fluorescein diacetate is carried out by a number of different enzymes, for instance protease, lipase, and esterase. The product of this enzymatic reaction is fluorescein, which could be visualized within cells by fluorescence microscopy or measured by spectrophotometry (Khadem *et al*., 2021).

Table 1. Some soil physicochemical properties of sugarcane and crop rotation fields under investigation.

Soil property	Control (Reference soil)	Soils under Sugarcane Monoculture	Soils under Crop Rotation
Sand %	32.4	31.93	29.48
Silt %	22.20	32.20	37.32
Clay %	45.40	35.87	33.20
Soil Texture	clay	Clay loam	Clay loam
B.D Mg/m^3	1.21	1.59	1.36
F.C m^3/m^3	0.41	0.27	0.30
OM %	2.15	2.31	2.90
SOC (g kg^{-1})	12.18	13.53	16.74
Labile C (g kg^{-1})	1.02	3.50	3.21
CEC ($cmol_c kg^{-1}$)	31.22	32.93	36.96
pH (1:2.5)	7.45	8.18	7.85
EC (dS m^{-1})	1.15	3.53	2.02
SAR %	3.73	8.98	5.06

4- Soil Heavy Metals Analysis

The dried soil samples were homogenized, sieved (< 0.6 mm) and ground in compliance with ISO-11464, and stored in sealed polyethylene bags before analysis. The dried soil samples were finely pulverised and sieved through a 0.149 mm mesh, and soil sample was weighed precisely to 0.05 g, laid in a microwave Teflon vessel, then digested in in 9.0 mL of HNO_3 and 3.0 mL of HF by using a microwave digestion unit system in accordance with the EPA method 3052 (USEPA, 1996). The concentration of Cd, Cr, Ni and Pb was determined in the resulted solutions by an inductively coupled plasma spectrometer (7700 e, Agilent Technologies, USA). For plants of sugarcane, wheat and maize, stem samples were washed with running tap water and then with ultrapure water, then oven-dried at 65±3 °C to a constant weight. Root samples were immersed in HCl 0.1 mol L^{-1} solution to get rid of metallic ions cling to the root surface and then cleaned with deionized and distilled water. All the crop samples were ground using a blender, sealed in polyethylene bags, and stored in a refrigerator at 20 °C. For crops, 0.5-g samples mixed in PTFE vessels with 2 mL concentrated HNO_3 and 1 mL H_2O_2 were soaked for 4 h and then digested for 6 h at 160 °C. The remained acid solutions were evaporated to almost dry and then diluted and filtered for measurement of total contents of Cd, Cr, Ni, and Pb by inductively coupled plasma mass spectrometer (7700e ICP-MS, Agilent Technologies, USA). For juice analyses, sugarcane stems were washed and rinsed with deionized distilled water, cleaned dry with a cloth, and then squeezed into juice. Heavy metals concentration of sugarcane juice (10 mL) was determined by 7700e ICP-MS in accordance with Tang *et al*., (2020). Reference standard ingredients and reagent blanks were used to guarantee high accuracy and to check if there were any inaccuracies during the analysis procedures (Tudi *et al*., 2021).

5- Estimation and assessment of heavy metals contamination characteristics.

In this study, to assess heavy metal pollution in soils and crops, the transfer factor (TF), the comprehensive transfer factor (CTF), the potential bioavailability of heavy metals for human (R_2), index of geo-accumulation (I*geo*), and Hakanson potential risk index method were used to assess the potential ecological risk associated with four heavy metals (Cd, Cr, Ni, and Pb) found in the sugarcane monoculture fields.

Transfer factor (TF):

The transfer factors (TF) of metals Cd, Cr, Ni and Pb (Kumar *et al*., 2020) from soils to plants were calculated as follows:

$TF_i = C_{i\,plant}$ **(dry wt. mg/kg) /** $C_{i\,soil}$ **(dry wt. mg/kg).**

The comprehensive transfer factor.

The comprehensive transfer factor (CTF) was calculated as:

$$CTF = \Sigma_{TFi} / 4$$

where Σ_{TFi} **includes** TF_{Cd}, TF_{Cr}, TF_{Ni}, **and** TF_{Pb}.

The potential bioavailability of heavy metals for human

In this study, to assess the potential bioavailability of heavy metals (R_2) is used as an indicative of bioavailability of heavy metals to humans through sugarcane juice intake (Wang *et al*., 2020). The ratio (R_2) of heavy metals in sugarcane juice samples (C_{juice}) to soil samples (C_s), expressed as: $R_2 = C_{juice} / C_s$

Index of geo-accumulation (I*geo*):

Index of geo-accumulation (I*geo*) was calculated as follows:

$$Igeo = Log_2 (Cm/1.5*Bm).$$

Where Cm is the measured concentration of the examined metal (m) in the soil samples and Bm is the geochemical background value of the same metal (m). The constant 1.5 is used for the possible variations of the background data due to the lithogenic effects. In this study, reference background values are based on the world soil average abundance of metals (Cd = 0.2, Cr = 80, Ni = 100 and Pb = 20).

The following seven grades of the I*geo* are distinguished (Muller *et al*., 1971): -

Grade	Value	Soil quality
1	Igeo ≤ 0	uncontaminated
2	0 < Igeo <1	uncontaminated to moderately contaminated
3	1 < Igeo <2	moderately contaminated
4	2 < Igeo <3	moderately to strongly contaminated
5	3 < Igeo <4	strongly contaminated
6	4 < Igeo <5	strongly to extremely contaminated
7	Igeo >5	extremely contaminated

The potential ecological risk (Hakanson Method).

Hakanson potential ecological risk method was used to judge soil quality and the potential ecological risk of metals contamination under sugarcane monoculture in soils. The method comprises:

(1) The single contamination coefficient or contamination factor, $C^i_f = C^i_s / C^i_n$,

where C^i_f is the contamination coefficient of a particular heavy metal, C_s^i is the measured data of soil heavy metals, and C_n^i is the reference value . In this study, the reference background values were used to accurately reflect the contamination levels at the alluvial soils in El-Minia Governorate, Egypt (Abd El-Azeim *et al*., 2016).

(2) The comprehensive contamination factor, $C_d = \sum C^i_f$.

(3) A particular heavy metal potential ecological risk index is calculated as follows: $E^i_r = T^i_r . C^i_f$, where T_r^i is the toxic response factor. According to the identical toxicological response factor proposed by Qu *et al*., (2012), Cd, Cr, Ni, and Pb, have toxic response factors of 30, 2, 5, and 5, respectively (Wang *et al*., 2013).

(4) The potential ecological risk index is $RI=\sum E_r^i$.

Soil degrees of contamination and corresponding standards of potential ecological risk in C_f^i, C_d, E_r^i and *RI* based on relevant studies (Wang *et al*., 2013) are as following:

Degree of contamination and grading standards for the potential ecological risk.

C_f^i	<1, non- contamination	≥1, <2, light	≥2, <3, moderate	≥3, heavy
C_d	<8,low	≥8,<16,moderate	≥16,<32,relatively high	≥32, very high
E_r^i <40, low	≥40,<80,moderate	≥80,<100,strong	≥100,<320,very strong	≥320, extremely strong
RI	<150, low	≥150, <300, moderate	≥300, <600, strong	≥600, very strong

6- Statistical Analysis

Descriptive statistics of minimum and maximum values, mean, standard deviation and coefficient of variance for raw soil data were established. Soil properties relations with heavy metal concentrations was determined using Pearson's correlation. Variance analysis was conducted using (SPSS for Windows, SPSS, Inc., Chicago, USA), and means of three replicates were separated by the least significant difference ($P \leq 0.05$) according to Duncan's test.

RESULTS AND DISCUSSION

1- Effects of long-term sugarcane monoculture on soil biological properties.

The highest and significant FDA hydrolysis value was found in crop rotation fields (266.67 mg/kg soil h^{-1}) followed by sugarcane monoculture fields (201.25 mg kg^{-1} $soil{\cdot}h^{-1}$), while the lowest value was found in the uncultivated soils (64.66 mg/kg soil h^{-1}) (Table 2). The increase of fluorescein diacetate (FDA) hydrolysis ranged from 86.25 to 201.25 mg kg^{-1} $soil{\cdot}h^{-1}$ in sugarcane monoculture fields, while the increase of diacetate fluorescein hydrolysis under crop rotation fields showed higher and significant values ranged from 207.25 to 266.67 mg kg^{-1} $soil{\cdot}h^{-1}$. In this study, generally soil microbial biomass and enzymatic activity was usually and significantly higher under crop rotation than sugarcane monoculture possibly due to the existence of decomposable organic materials in soils available for microbiological utilization and enzymatic reactions (Freitas *et al.* 2017; Carvalho *et al*., 2018). Associating some soil physicochemical properties under sugarcane monoculture agricultural systems and crop rotation, the main differences to explain this direction are lower content of SOM, lack of various sources of organic substrates on soil microbial biomass, lower plant diversity and lowest organic inputs following sugarcane residues burning in sugarcane fields (Novak *et al.* 2017; Farhate, *et al*., 2020; Melo *et al*., 2020). The FDA activity was significantly and positively correlated with soil properties including SOM, SOC and CEC.

The increase in soil FDA is partially accredited to the higher organic substrates availability or improved physical conditions under crop rotation agricultural system (Carvalho *et al*., 2018 and Melo *et al*., 2020). The lower soil SOM and SOC content under sugarcane monoculture system, compared with the crop rotation, confirmed the role of different agricultural practices in contributing to the increased soil microbial and enzymatic activities. Schnürer and Rosswall (1982), indicated that the hydrolysis of FDA is correlated with soil microbial biomass and reflects the soil microbial activity. These findings are consistent with earlier studies, which have found higher soil microbial community under vegetation and cropland than monoculture of sugarcane (Novak *et al.* 2017; Freitas *et al.* 2017). Carvalho *et al*., (2018) and Melo *et al*., (2020) reported some explanations for higher soil microbial biomass under vegetation and cropland over sugarcane monoculture: a) higher vegetal variety and lowest disparity in temperature and moisture (b) higher organic material contributions (Lopes *et al.* 2010). Soil is a dynamic natural resource and a significant part of the terrestrial ecosystem, and supports all terrestrial life forms. Therefore, under monoculture of sugarcane, numerous problems may arise without proper soil management practices, such as reduced soil fertility and loss of soil microbial and enzymatic activities.

Table 2. Fluorescein diacetate hydrolysis (FDA) of alluvial soils under sugarcane monoculture and crop rotation and correlation matrix between FDA and selected soil properties.

Soil samples	FDA hydrolysis activity mg kg^{-1} soil h^{-1}		SOM (%)		Clay (%)	
	SM	**CR**	**SM**	**CR**	**SM**	**CR**
1	139.50	266.67	0.47**	0.88**	0.49**	0.77**
2	131.25	210.45	0.32*	0.52**	0.33*	0.52**
3	140.50	259.75	0.49**	0.76**	0.56**	0.74**
4	140.50	243.25	0.49**	0.72**	0.56**	0.71**
5	115.89	219.89	0.36**	0.76**	0.30*	0.66**
6	125.25	207.25	0.41*	0.46*	0.42**	0.60*
7	130.50	266.56	0.44**	0.88**	0.41**	0.41**
8	201.25	222.67	0.62**	0.65**	0.65**	0.45**
9	144.78	235.25	0.35**	0.77**	0.39**	0.57**
10	161.56	214.75	0.39**	0.67**	0.35**	0.41**
11	144.25	213.25	0.35**	0.63**	0.39**	0.39**
12	177.50	214.75	0.60**	0.68**	0.40**	0.41**
13	86.25	225.90	0.24^{ns}	0.71**	0.41**	0.48**
14	99.25	233.75	0.30*	0.75**	0.45**	0.55**
15	110.75	211.89	0.31*	0.61**	0.38**	0.43**
Reference soil	64.66	64.66				

Descriptive Statistical Analysis (FDA)		
Soils under	Sugarcane	Crop rotation
Average	136.59	229.73
Max	201.25	266.67
Min	86.25	207.25
S.D	29.10	20.57
C.V%	21.30	8.95

***p < 0.05, **p < 0.01*, ns not significant. SM = Sugarcane monoculture; CR = Crop rotation.**

Amongst different soil quality indicators, hydrolysis of FDA enzyme activity is one of the most important and sensitive soil biological indicators, relating to soil health and fertility. Hydrolysis of FDA is anticipated as the best soil microbiological redox-systems indicator and could be considered as good and adequate oxidative parameter of microbial activities in soils (Patle *et al*., 2018). Therefore, using soil microbial indicators for assessment of soil quality is very sensitive approach which is responding quickly to the environmental variations (Patle *et al*., 2018; Melo *et al*., 2020; Khadem *et al*., 2021). Aseri and Tarafdar (2007), reported a strong correlation ($r^2 = 0.61$; $p < 0.01$) between the FDA hydrolysable enzyme activity and microbial biomass. Their findings verified that FDA hydrolysable enzyme activity is a potential biological indicator of arid soils and already considered as a biological indicator.

Different soil land-use alter soil microbial characteristics and mensuration the change of soil properties owing to the intensity of agricultural farming system has been a major tool for monitoring soil quality (Neves *et al*., 2007). Biochemical soil properties, for instance the amount of microbial biomass carbon and microbial biomass nitrogen, in addition to fluorescein diacetate hydrolysis (FDA) ratios, are very delicate to changes in soils because they are directly affected by soil physicochemical disorders caused by intensive cultivation and the intensive application of fertilizers and pesticides (Bogres *et al*., 2014; Abd El-Azeim *et al*., 2020; Tang *et al*., 2020; Khadem *et al*., 2021). According to the farming system, sugarcane causes a heavy environmental impact. Under long term sugarcane production, Bogres *et al*., (2014) quantified considerable decline in soil organic matter (SOM) contents consequently, sugarcane caused a significant environmental impact on soil quality. In addition, sugarcane burning has reflective impacts as it declines the soil organic matter, leaving it exposed to decomposition and erosion, causing heavy pollution and thus impacting soil microorganisms (Borges *et al*., 2014).

2- Assessment and estimation of soil and plant contamination with heavy metals.

Heavy metals in soils under sugarcane monoculture and crop rotation.

Heavy metals of Cd, Cr, Ni and Pb distribution features with a descriptive statistical summary at soil rhizosphere depth of 0–30 cm of the studied alluvial soils in Abo-Qurqas district, Egypt is given in Table 3. Nickel (Ni) had the highest average concentration (138.89 mg kg^{-1}), followed by Pb (122.76 mg kg^{-1}), Cr (111.46 mg kg^{-1}), and Cd (27.03 mg kg^{-1}) in sugarcane monoculture fields, while in crop rotation; Pb had highest average concentration (48.16 mg kg^{-1}), followed by Ni (47.6 mg kg^{-1}), Cr (27.4 mg kg^{-1}) and Cd (10.46 mg kg^{-1}). Compared to crop rotation, soil samples of sugarcane fields possessed significantly higher heavy metal values for all the measured elements, which illustrated that soils under sugarcane monoculture were more susceptible to heavy metal accumulation.

Under sugarcane monoculture, the four heavy metals in most soil samples had soil concentrations greater than the levels stipulated by the soil environmental quality standard regulations (Alloway, 1995; Abd El-Azeim *et al*., 2016; Tang *et al*., 2020) and critical values for plant growth (Linzon, 1978). This varied range of heavy metals content in soils under sugarcane monoculture is apparently related to soil texture and might be owing to metals deposited sediments in Nile floodplains and continuous addition of polluted irrigation water and artificial and organic fertilizers, which is in a good agreement with results by Abd El Azeim *et al*., (2016) and Tang *et al*., (2020). Results by Tang *et al*., (2020), revealed that the mean contents of Cu, Cr, Cd, As, and Zn in rice soils were significantly lower than those in sugarcane soils and rice soils were mainly contaminated by Cd. Cadmium (Cd) and Chromium (Cr) were the main pollutants in sugarcane soils (Tang *et al*., 2020).

Table 3. Descriptive statistics of heavy metal concentrations (mg kg^{-1}) in soils of sugarcane monoculture (SM) and crop rotation (CR).

Soil samples	Concentration, mg kg^{-1}							
	Cadmium Cd		Chromium Cr		Nickel Ni		Lead Pb	
	SM*	CR	SM	CR	SM	CR	SM	CR
1	19.00	12.00	79.5	35.50	118.00	92.50	45.00	18.50
2	26.50	20.00	42.50	25.00	116.00	86.00	31.00	26.00
3	21.00	19.50	131.00	27.50	121.00	44.50	114.50	38.00
4	21.00	6.50	30.00	14.50	116.00	35.00	187.50	113.50
5	30.00	18.00	117.50	6.50	120.00	58.50	211.00	53.00
6	30.50	14.50	165.5	22.50	118.50	69.00	116.50	55.50
7	21.00	13.00	189.5	56.0	127.50	157.50	121.50	70.50
8	40.50	4.00	124.50	23.00	17.45	6.50	126.50	59.50
9	28.00	10.50	112.0	38.50	311.50	6.50	111.50	49.50
10	32.0	9.50	141.00	37.00	210.50	39.00	114.50	55.50
11	28.50	6.50	121.50	15.00	129.50	9.50	219.00	61.50
12	35.00	9.50	35.00	22.50	123.00	11.50	114.50	63.00
13	20.5	4.00	151.00	25.00	186.00	39.50	116.50	25.50
14	30.50	7.50	167.5	37.50	145.00	21.00	177.00	16.50
15	21.50	2.00	64.00	25.00	123.50	37.50	35.00	16.50
Reference soil	0.21		8.32		22.15		6.25	
Descriptive Statistical Analysis								
Average	27.03	10.46	111.46	27.40	138.89	47.60	122.76	48.16
Max	40.50	20.00	189.50	56.00	311.5	157.50	219.00	113.50
Min	19.00	2.00	30.00	6.50	17.45	6.50	31.00	16.50
S.D mg kg^{-1}	6.28	5.68	50.55	12.07	62.79	40.87	57.80	25.93
C.V%	23.24	54.27	45.35	44.08	45.21	85.88	47.08	53.85

***SM = Sugarcane monoculture; CR = Crop rotation.**

Results indicated that sugarcane monoculture agricultural practices induced higher significant increases in the soil heavy metal contents of Cd, Cr, Ni and Pb over the crop rotation agricultural practices and the reference soil samples. Heavy metal concentrations in soils under sugarcane monoculture followed the order Ni > Pb > Cr > Cd, while, under crop rotation the order was Pb > Ni > Cr > Cd. Sugarcane monoculture agricultural system induced heavy metals concentrations in soils above the quality reference values (QRVs), critical values for plant growth (CVPs), soil background concentrations (SBCs), for soils in El-Minia Governorate, Egypt, (Alloway, 1995; Abd El-Azeim *et al*., 2016) in at least ninety percent of the surveyed soil samples (Figure 1). The only exception was that nickel Ni concentration in soils under sugarcane monoculture was below the critical values for plant growth (CVPs).

In contrast, heavy metals of Cr, Ni, and Pb brought in soils by crop rotation system were often under these quality indicators except for Cd. This clearly suggests that under sugarcane monoculture, anthropogenic inputs through agricultural activities have increased heavy metal concentrations in such soils to grades surpassing the lithogenic contribution of weathering. Significant increments in heavy metal concentration in agricultural soils under different farming systems have been reported in several parts of the world (Sun *et al*. 2013; da Silva *et al*., 2016; Tang *et al*., 2020; Wang *et al*., 2020; Qin *et al*., 2021). In sugarcane plantation areas of Brazil, the Cd concentration for areas of high Cd levels was probably due to pollutants in phosphatic fertilizers. The assessed input of Cd from this fertilization source differs from 38 g ha^{-1} to 340 g ha^{-1} (Yadav *et al*., 2010).

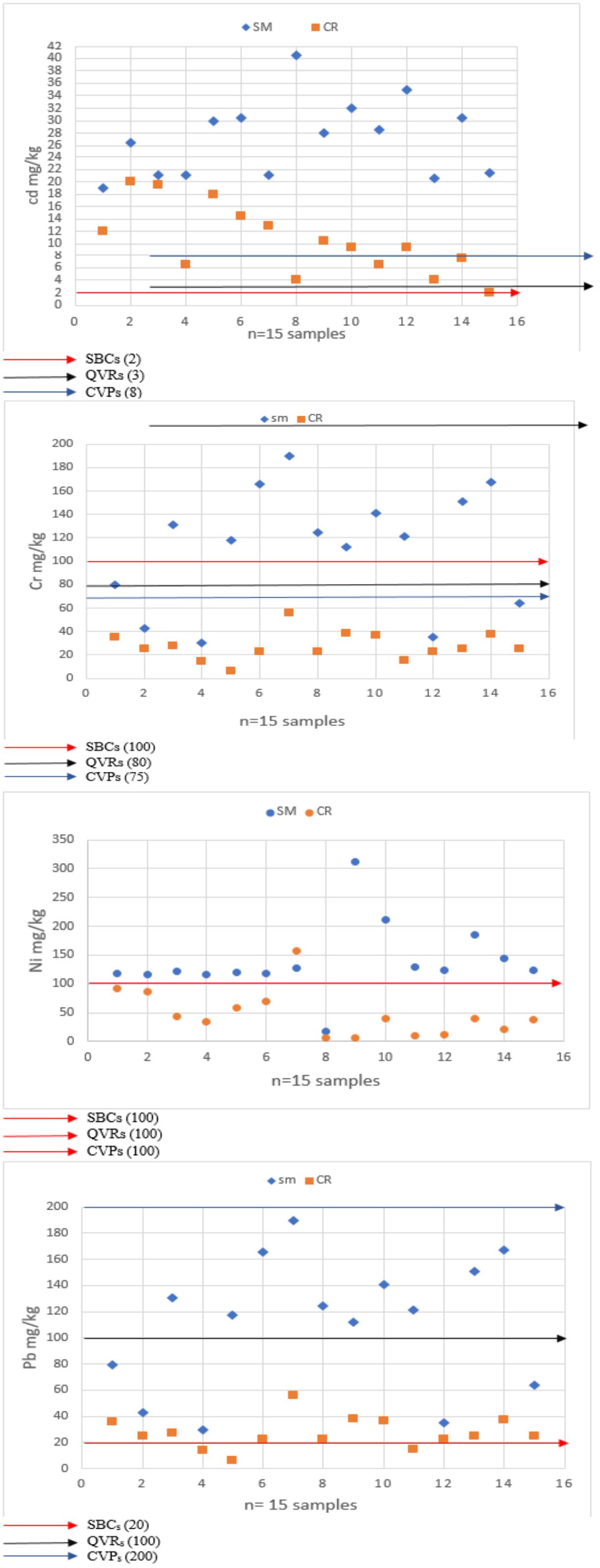


Figure 1. Soil heavy metal concentrations in sugarcane and crop rotation fields as compared to national and international soil quality standard values. (QRVs) = quality reference values, (CVPs) = critical values for plant growth, (SBCs) = soil background concentrations. SM = Sugarcane monoculture; CR = Crop rotation.

Based on the national and worldwide regulation apropos heavy metal concentrations in agricultural soils (Alloway, 1995; Conama 2009; Abd ElAzeim *et al*., 2016), sugarcane monoculture fields can pose an undesirable risk to human health since their Cd concentrations in soils are above 19.0 mg kg^{-1}. Cadmium is one of the most toxic heavy metals and enters agroecosystems through industrial effluents and the unwise use of phosphate fertilizers (da Silva *et al*., 2016; Tang *et al*., 2020). The existence of cadmium in phosphate fertilizers is because of its natural occurrence in phosphate rocks used for fertilizer manufacturing (Kabata-Pendias 2011). Cadmium had the highest potential of ecological contamination index in agricultural lands across China and the cumulation was also linked with fertilization (Niu *et al*., 2013). Changes in metabolic process in sugarcane plants were observed after posing it to different concentrations of lead (Rai *et al.* 2005; Kumar *et al*., 2020).

A typical cadmium concentration of plants can range from 0.1 up to 2.4 ppm (Alloway 1990). Cadmium cumulates in farmable soils through the application of soil amendments like phosphatic fertilizers and biosolids, which are known to contain Cd levels of 7.3-170 ppm and <1-3410 ppm (Alloway 1990), respectively.

Heavy metals in crops and sugarcane juice.

The descriptive statistical analyses of the heavy metal concentrations in sugarcane, wheat and maize crops are presented in Table 4. The average concentrations of Cd, Cr, Ni and Pb in sugarcane were 1.72 mg/kg, 2.11 mg/kg, 5.62 mg/kg, and 7.73 mg/kg, respectively, and their corresponding values in wheat under crop rotation system were 1.01 mg/kg, 1.04 mg/kg, 51.38 mg/kg, and 27.19 mg/kg, while in maize under crop rotation system were 1.07 mg/kg, 2.23 mg/kg, 52.64 mg/kg, and 34.82 mg/kg. The average concentrations of heavy metals in crops under crop rotation system were significantly higher than those in sugarcanes except for Cd albeit that Cd contents whether in sugarcane, wheat or maize un-exceeded the food safety limits (Alloway, 1990; Tang *et al*., 2020). These results indicated that sugarcane is the kind of a crop capable to grow in regions where metals have cumulated in soils (Yadav *et al*., 2010; Tang *et al*., 2020).

In addition, under sugarcane monoculture the sugarcane juice contained considerable amounts of Cd, Cr, Ni and Pb. The heavy metal concentrations in sugarcane juice followed the trend Ni < Pb < Cr < Cd (Table 5). The contents of cadmium, chromium, nickel and lead in sugarcane juice have been found at levels above their permissible limits indicating a potential concern for people who eat large amounts of cane in these areas (Yadav *et al*., 2010; Kamau, 2016; Farhate, *et al*., 2020; Wang *et al*., 2020). Recorded very high values of the coefficient variance CVs indicated that the content of the heavy metals varied substantially in both fields under different agricultural systems. The current results suggest that the outdated agricultural practices used to grow the sugarcane may have resulted in translocating metals from roots to edible parts of sugarcane and juice. However, to assess heavy metals in sugarcane juice, and their ratios joined with soil concentrations (R_2), it was estimated that Ni had a predominant high level compared to its corresponding values in soils (i.e., R_2 was 0.053 g/kg), followed by Pb > Cd > Cr (Table 5). Wang *et al*., (2020) stated that the highest rank of both cancer and non-carcinogenic health risks posed by heavy metals on children through different pathways was drinking polluted juice from contaminated sugarcane followed by oral intake, then dermal contact and inhalation. For non-carcinogenic health risks, chromium and cadmium in the juice of sugarcane posed the most significant risks. Whereas, arsenic and lead posed the highest risks through non-dietary exposure routes.

Table 4. Heavy metal concentrations in sugarcane, wheat and maize crops and its descriptive statistical analyses.

Soil samples	Concentration (mg kg^{-1} dry matter)											
	Cd			Cr			Ni			Pb		
1	**sugar**	**wheat**	**maize**	**sugar**	**wheat**	**maize**	**sugar**	**wheat**	**maize**	**sugar**	**wheat**	**maize**
2	1.88	0.26	0.82	2.17	1.26	1.23	7.82	72.37	67.07	6.50	15.40	28.35
3	1.77	0.67	0.72	2.07	1.11	1.08	5.90	40.97	36.23	8.70	15.20	27.70
4	1.68	0.69	1.07	2.04	1.31	2.27	7.70	81.03	71.50	13.07	14.37	25.20
5	1.95	0.98	0.96	2.22	1.16	1.14	7.30	50.00	40.50	9.47	16.30	29.80
6	1.81	0.86	0.84	2.08	1.11	2.08	7.70	40.63	32.17	8.93	31.53	31.26
7	1.74	1.17	1.15	2.02	1.29	1.25	2.13	52.80	77.37	9.27	30.43	36.33
8	1.97	1.07	1.05	2.24	1.15	4.10	1.51	51.70	46.83	8.20	40.47	38.60
9	1.81	0.98	0.95	2.06	1.08	2.05	6.87	36.27	32.17	2.80	42.40	37.93
10	1.74	1.22	1.20	2.02	1.34	1.31	5.77	19.17	73.23	3.50	22.50	38.30
11	1.95	1.11	1.09	2.23	1.18	2.16	7.93	58.53	53.10	5.70	33.37	38.40
12	1.83	1.23	1.20	2.10	1.30	3.28	8.30	62.17	77.33	8.00	36.23	35.03
13	1.72	1.11	1.09	2.04	1.16	3.15	2.77	51.80	46.43	12.10	36.03	34.97
14	1.11	1.41	1.45	2.23	2.29	3.25	3.97	62.33	56.43	7.43	13.83	41.8
15	1.01	1.25	1.25	2.10	2.19	2.14	4.47	41.27	35.23	6.90	37.87	41.63
Descriptive Statistical Analysis												
Average	1.72	27.03	10.46	2.11	111.46	27.40	5.62	138.89	47.60	7.73	122.76	48.16
Max	1.97	40.50	20.00	2.24	189.50	56.00	8.30	311.5	157.50	13.07	219.00	113.50
Min	1.01	19.00	2.00	2.02	30.00	6.50	1.51	17.45	6.50	2.80	31.00	16.50
S.D mg kg^{-1}	0.28	6.28	5.68	0.08	50.55	12.07	2.29	62.79	40.87	2.79	57.80	25.93
C.V%	16.57	23.24	54.27	3.98	45.35	44.08	40.78	45.21	85.88	36.21	47.08	53.85

Table 5. Descriptive statistical analyses of heavy metal concentrations in soils (C_s), sugarcane juice (C_{juice}) and the potential bioavailability of heavy metals (R_2).

Soil samples	Concentration (mg kg^{-1})											
	Cd			Cr			Ni			Pb		
	Juice	**soil**	R_2	**Juice**	**soil**	R_2	**Juice**	**soil**	R_2	**Juice**	**soil**	R_2
1	0.22	19.00	0.011	0.22	79.50	0.002	0.60	118.00	0.005	0.33	45.00	0.007
2	0.05	26.50	0.001	0.15	42.50	0.003	0.77	116.00	0.006	0.63	31.00	0.020
3	0.02	21.00	0.000	0.14	131.00	0.001	0.63	121.00	0.005	0.77	114.50	0.006
4	0.08	21.00	0.003	0.23	30.00	0.007	0.43	116.00	0.003	0.43	187.50	0.002
5	0.04	30.00	0.001	0.09	117.50	0.000	0.97	120.00	0.008	0.43	211.00	0.002
6	0.15	30.50	0.004	0.03	165.50	0.000	0.80	118.50	0.006	0.97	116.50	0.008
7	0.09	21.00	0.004	0.25	189.50	0.001	0.47	127.50	0.003	0.80	121.50	0.006
8	0.04	40.50	0.000	0.08	124.50	0.000	0.93	17.45	0.053	0.83	126.50	0.006
9	0.05	28.00	0.001	0.03	112.00	0.000	0.23	311.50	0.000	0.63	111.50	0.005
10	0.08	32.00	0.002	0.25	141.00	0.001	0.93	210.50	0.004	0.97	114.50	0.008
11	0.07	28.50	0.002	0.10	121.50	0.000	0.27	129.50	0.002	0.20	219.00	0.000
12	0.07	35.00	0.002	0.04	35.00	0.001	0.77	123.00	0.006	0.77	114.50	0.006
13	0.12	20.50	0.005	0.24	151.00	0.001	0.73	186.00	0.003	0.50	116.50	0.004
14	0.04	30.50	0.001	0.12	167.50	0.000	0.87	145.00	0.006	0.60	177.00	0.003
15	0.14	21.50	0.006	0.15	64.00	0.002	0.60	123.50	0.004	0.47	35.00	0.013
Descriptive Statistical Analysis												
Average	0.08	27.03	0.003	0.14	111.46	0.001	0.66	138.89	0.008	0.62	122.76	0.006
Contamination degree			low			low			low			low
Max	0.22	40.50	0.011	0.25	189.50	0.007	0.97	311.50	0.053	0.97	219.00	0.020
Min	0.02	19.00	0.000	0.03	30.00	0.000	0.23	17.45	0.000	0.20	31.00	0.000
S.D mg kg^{-1}	0.05	6.28	0.002	0.08	50.55	0.001	0.23	62.79	0.012	0.22	57.80	0.004
C.V%	63.60	23.24	82.31	57.09	45.35	105.91	35.13	45.21	157.23	36.87	47.08	70.57

Heavy metals are natural nondegradable environmental components and considered a potential soil and aquatic contaminants. Large amounts of these heavy metals are cumulated as a result of land-based anthropogenic activities in soils and aquatic ecosystems (Shah *et al*. 2020; Wang *et al*., 2020; Inamuddin, *et al*., 2021). Nowadays, heavy metal deposits have become a case of serious anxiety due to their continuous increase in soil and aquatic environment (Wang *et al*., 2020; Qin *et al*., 2021). Heavy metals are highly soluble in water and can easily be absorbed by plants and the living organisms which pose a real threat for them owing to heavy metal cumulation in the food chain above toxicological level in addition to their nonbiodegradability (Yadav *et al*., 2010; Kamau 2016; Inamuddin, *et al*., 2021).

Heavy metals potential ecological risk assessment in soils and crops

To relate the potential contamination characteristics of heavy metals in sugarcane soils and plants at the sugarcane belt of Abo-Qurqas district, the transfer factor (TF), the comprehensive transfer factor (CTF), index of geo-accumulation (I*geo*), the potential ecological risk indices (Hakanson method) were used to analyze Cd, Cr, Ni, and Pb contamination and to assess the corresponding ecological risks for soil environment and plants.

Transfer factor (TF) and comprehensive transfer factor (CTF) values of heavy metals.

The average transfer factor TF values of Cd, Cr, Ni, and Pb in sugarcane were 0.066, 0.025, 0.063, and 0.084 mg/kg, respectively, and were 0.158, 0.062, 0.0149, and

0.0716 mg/kg in wheat samples, and were 0.160, 0.102, 2.660, and 0.996 mg/kg in maize samples (Table 6). Under sugarcane monoculture, the comprehensive transfer factor CTF ($\Sigma_{TFi}/4$) values for transfer factors were always less than (<1) reflecting low contamination level and transfer from soil rhizosphere. In contrast, under crop rotation, the comprehensive transfer factor values were more than (>1) in at least half of the plant samples reflecting high contamination levels. Compared to sugarcane plant samples, wheat and maize samples had significantly higher TF values for all measured elements, indicating that plants subject to the crop rotation system were more likely to accumulate heavy metals in plant parts than in sugarcane despite higher concentrations of these heavy metals in the soils of sugarcane. Preceding studies also demonstrated that cereal crops were more effectual to take up heavy metal contaminants in both edible and inedible part than other terrestrial crops (Norton *et al.* 2014; Tang *et al.*, 2020).

Table 6. Heavy metal pollution and environment risk assessment of the sugarcane, wheat plants and soils by transfer factor (TF) and comprehensive transfer factor (CTF).

Soil samples	Sugarcane monoculture TF and CTF					Cont. level	Crop rotation (wheat) TF and CTF					Cont. level
	Cd	Cr	Ni	Pb	∑ *TF*		Cd	Cr	Ni	Pb	∑ *TF*	
1	0.098	0.027	0.066	0.144	0.083	Low	0.021	0.035	0.782	0.832	0.417	Low
2	0.066	0.048	0.050	0.280	0.111	Low	0.033	0.044	0.476	0.584	0.284	Low
3	0.080	0.015	0.063	0.114	0.068	Low	0.035	0.047	1.820	0.378	0.570	Low
4	0.092	0.074	0.062	0.050	0.069	Low	0.150	0.08	1.428	0.143	0.450	Low
5	0.060	0.017	0.064	0.042	0.045	Low	0.047	0.170	0.694	0.594	0.376	Low
6	0.057	0.012	0.017	0.079	0.041	Low	0.080	0.057	0.765	0.548	0.362	Low
7	0.093	0.011	0.011	0.067	0.045	Low	0.082	0.020	0.328	0.574	0.251	Low
8	0.044	0.016	0.393	0.022	0.118	Low	0.245	0.046	5.580	0.712	1.645	High
9	0.062	0.018	0.018	0.031	0.032	Low	0.116	0.034	2.949	0.454	0.888	Low
10	0.060	0.015	0.037	0.049	0.040	Low	0.116	0.031	1.500	0.601	0.562	Low
11	0.064	0.017	0.064	0.036	0.045	Low	0.189	0.086	6.544	0.589	1.852	High
12	0.049	0.058	0.022	0.105	0.058	Low	0.116	0.051	4.504	0.571	1.310	High
13	0.054	0.014	0.021	0.063	0.038	Low	0.352	0.091	1.577	0.542	0.640	Low
14	0.033	0.012	0.030	0.038	0.028	Low	0.166	0.058	1.965	2.295	1.121	High
15	0.089	0.031	0.034	0.154	0.077	Low	0.625	0.085	1.327	1.333	0.842	Low
Descriptive Statistical Analysis												
Average	0.066	0.025	0.063	0.084	0.060		0.158	0.062	2.149	0.716	0.771	
Cont. degree	Low	Low	Low	Low	Low		Low	Low	High	Low	Low	
Max.	0.098	0.074	0.393	0.28	0.118		0.625	0.17	6.544	2.295	1.852	
Min.	0.033	0.011	0.011	0.022	0.028		0.021	0.02	0.328	0.143	0.251	
S.D mg/kg^{-1}	0.019	0.019	0.093	0.067	0.027		0.156	0.036	1.915	0.504	0.501	
C.V%	29.22	74.83	147.06	79.74	45.91		98.99	59.31	89.13	70.36	65.03	

Index of geo-accumulation (I*geo*).

Under sugarcane monoculture, the geoaccumulation ecological risk (I*geo*) values for the studied elements were in average order of Cd (6.45) > Pb (1.82) > Ni (-0.29) > Pb (-0.30). Under crop rotation, the ecological risk (I*geo*) values for the studied elements were in average order of Cd (4.87) > Pb (0.46) > Ni (-2.21) > Pb (-2.28) (Table 7). The ecological risk (I*geo*) values revealed that the studied metals in the sugarcane soil were graded from extremely for Cd, to moderately polluted status for Pb, to uncontaminated polluted status for Cr and Nickel. The I*geo* values revealed that the studied metals in the rotational crop soils were graded from strongly polluted status for Cd, to moderately polluted status for Pb, to uncontaminated polluted status for Cr and Nickel. Among these toxic heavy metals, Cd showed significant accumulation in both sugarcane and crop soils suggesting high pollutions of Cd can translocate from soil rhizosphere to crops. By contrast, the I*geo* average values of Cr, Pb, and Ni were ranged from zero to less than one under both farming systems indicating little environmental risk.

According to the geo-accumulation index (I*geo*) values, the average values of Cd in both sugarcane fields and crop rotation showed extremely contamination level and these values also, confirmed that heavy metal pollution levels of soils collected from sugarcane were greater than those from crop rotation. The contamination order of the studied heavy metals was Cd＞Pb＞Cr＞Ni under both sugarcane monoculture and crop rotation systems. Wang *et al*., (2018) revealed that Pb, Cd, As, and Zn were the major metal pollutants in sugarcane soils along the Huanjiang River, and their concentrations in all soil samples were higher than the heavy metal background value for Guangxi, indicating that sugarcane soils were polluted severely. In addition, Pb and Cd posed the highest environmental risk and constant threat to the ecosystem and human health.

Table 7. Environment risk assessment of sugarcane and crop rotation soils by the geoaccumulation ecological risk (I*geo*).

Soil samples	Geoaccumulation ecological risk (I*geo*)							
	Cadmium Cd		Chromium Cr		Nickel Ni		Lead Pd	
	SM*	CR	SM	CR	SM	CR	SM	CR
1	5.98	5.32	-0.59	-1.75	-0.34	-0.69	0.58	-0.69
2	6.46	6.05	-1.49	-2.26	-0.37	-0.80	0.04	-0.20
3	6.12	6.02	0.12	-2.12	-0.30	-1.75	1.93	0.34
4	6.12	4.43	-2.00	-3.04	-0.37	-2.09	2.64	1.91
5	6.64	5.90	-0.03	-4.20	-0.32	-1.35	2.81	0.82
6	6.66	5.59	0.46	-2.41	-0.34	-1.12	1.95	0.88
7	6.12	5.43	0.65	-1.09	-0.23	0.07	2.01	1.23
8	7.07	3.73	0.05	-2.38	-3.10	-4.52	2.07	0.98
9	6.54	5.12	-0.09	-1.64	1.05	-4.52	1.89	0.72
10	6.73	4.98	0.23	-1.69	0.48	-1.94	1.93	0.88
11	6.56	4.43	0.01	-3.00	-0.21	-3.98	2.86	1.03
12	6.86	4.98	-1.77	-2.41	-0.28	-3.70	1.93	1.07
13	6.09	3.73	0.33	-2.26	0.31	-1.92	1.95	-0.23
14	6.66	4.64	0.48	-1.67	-0.04	-2.83	2.56	-0.86
15	6.16	2.73	-0.90	-2.26	-0.28	-2	0.22	-0.86
Descriptive Statistical Analysis								
Average	6.45	4.87	-0.30	-2.28	-0.29	-2.21	1.82	0.46
I*geo* Cont. degree	Extremely	strongly	Uncontaminated				moderately	
Max	7.07	6.05	0.65	-1.09	1.05	0.07	2.86	1.91
Min	5.98	2.73	-2	-4.20	-3.10	-4.52	0.04	-0.86
S.D	0.33	0.94	0.85	0.74	0.87	1.42	0.87	0.84
C.V%	5.13	19.37	-283.08	-32.41	-301.02	-64.23	47.82	180.47

***SM = Sugarcane; CR = Crop rotation.**

The Hakanson potential ecological risks.

The contamination factor (C_f^i) demonstrated that the sugarcane monocultured soils were heavy polluted with Cd, and Pb, while noncontaminated to light polluted with Cr and Ni (Table 8). Whereas, the contamination factor (C_f^i) demonstrated that the crop rotation soils were heavy polluted with Cd, but moderately with Pb, while noncontaminated with Cr and Ni. The contamination factor demonstrated that the reference uncultivated soil was noncontaminated with Cd, Cr, Ni and Pb. Agricultural fields under sugarcane monoculture showed contamination factor (C_f^i) of heavy metals Pb and Cd average of 6.13 and 13.51 indicating a very high pollution ($C_f^i > 3$), while C_f^i of heavy metals Cr, and Ni average of 1.39 to 1.38 indicating a light pollution ($C_f^i > 1 < 2$). The C_f^i of crop rotation soils average of Cd and Pb was 5.23 and 2.40, indicating heavy for Cd to moderate pollution for Pb. These results showed that Cd, Cr, Ni and Pb made a large contribution to pollution in the case of sugarcane monoculture fields compared to crop rotation fields. The single contamination factor (C_f^i) proposed by Hakanson was used to assess the enrichment of the investigated heavy metals in the soils and to measure the pollution levels of sugarcane monoculture fields (Wang *et al*., 2013, Wang *et al*., 2018; Tang *et al*., 2020).

The degree of soil contamination (C_d) under sugarcane monoculture ranged from 13.92 to 28.30 with an average value of 22.43, reflecting relatively high contamination level, while under crop rotation the degree of soil contamination ranged from 2.51 to 12.47 with an average value of 8.46, reflecting moderate contamination level as shown in Table 8. The order of contamination of the studied heavy metals was Cd＞ Pb＞ Cr＞ Ni, under sugarcane while, the order of contamination at crop rotation sites was, Cd> Pb > Ni> Cr. Under sugarcane monoculture, the average value of the studied four heavy metals contamination coefficients (C_f^i) were between 1.38 and 13.51 indicating a slight level of contamination in the case of Ni and Cr and heavy contamination level in the case of Cd and Pb. Whereas, the average value of heavy metal contamination coefficients was between 0.34 and 5.23 indicating a slight level of contamination in the case of Cr and Ni and moderate contamination level in the case of Pb.

Table 8. Environment risk assessment of sugarcane and crop rotation soils by the Hakanson potential ecological risks (contamination factor (C_f^i) comprehensive contamination factor (C_d).

Land use	sugarcane monoculture					Contamination level	Crop rotation					Cont. level
	Cd	Cr	Ni	Pb	C_d		Cd	Cr	Ni	Pb	C_d	
1	9.50	0.99	1.18	2.25	13.92	moderate	6.00	0.44	0.92	0.92	8.29	moderate
2	13.25	0.53	1.16	1.55	16.49	Relatively high	10.00	0.31	0.86	1.30	12.47	moderate
3	10.50	1.63	1.21	5.72	19.07	Relatively high	9.75	0.34	0.44	1.90	12.43	moderate
4	10.50	0.37	1.16	9.37	21.41	Relatively high	3.25	0.18	0.35	5.67	9.45	moderate
5	15.00	1.46	1.20	10.55	28.21	Relatively high	9.00	0.08	0.58	2.65	12.31	moderate
6	15.25	2.06	1.18	5.82	24.32	Relatively high	7.25	0.28	0.69	2.77	10.99	moderate
7	10.50	2.36	1.27	6.07	20.21	Relatively high	6.50	0.70	1.57	3.52	12.3	moderate
8	20.25	1.55	0.17	6.32	28.30	Relatively high	2.00	0.28	0.06	2.97	5.32	low
9	14.00	1.40	3.11	5.57	24.09	Relatively high	5.25	0.48	0.06	2.47	8.27	moderate
10	16.00	1.76	2.10	5.72	25.59	Relatively high	4.75	0.46	0.39	2.77	8.37	moderate
11	14.25	1.51	1.29	10.95	28.01	Relatively high	3.25	0.18	0.09	3.07	6.60	low
12	17.50	0.43	1.23	5.72	24.89	Relatively high	4.75	0.28	0.11	3.15	8.29	moderate
13	10.25	1.88	1.86	5.82	19.82	Relatively high	2.00	0.31	0.39	1.27	3.98	low
14	15.25	2.09	1.45	8.85	27.64	Relatively high	3.75	0.46	0.21	0.82	5.25	low
15	10.75	0.80	1.23	1.75	14.53	moderate	1.00	0.31	0.37	0.82	2.51	low
descriptive Statistical analysis												
Average	13.51	1.39	1.38	6.13	22.43		5.23	0.34	0.47	2.40	8.46	
Contamination degree	heavy	light	light	heavy	Relatively high		heavy	Non	Non	moderate	moderate	
Max	20.25	2.36	3.11	10.95	28.30		10.00	0.7	1.57	5.67	12.47	
Min	9.50	0.37	0.17	1.55	13.92		1.00	0.08	0.06	0.82	2.51	
S.D mg/kg^{-1}	3.14	0.63	0.62	2.89	4.94		2.84	0.15	0.40	1.29	3.25	
C.V%	23.24	45.35	45.21	47.08	22.05		54.27	44.08	85.88	53.85	38.43	

Cadmium (Cd) had the highest contamination coefficient, in both soils under sugarcane monoculture (13.51) and crop rotation (5.23), indicating severe heavy contamination. Consequently, constricted pollution control and management practices are immediately needed to avoid the increase of Cd contamination and to limit potential environmental damage under sugarcane monoculture system. The degree of contamination of Cd in the reference soil (uncultivated control) was 1.8, which indicates a light level of contamination. Tang *et al*., (2020) revealed that, the mean sugarcane soil single pollution index (SPIs) of different elements, were in the following decreasing order of Cd (1.48) > Cr (1.22) > As (0.78) > Zn (0.53) > Cu (0.19), where the contamination of cadmium and chromium (mean SPIs > 1) should be of a potential concern.

Results for the potential ecological risk indices of the studied heavy metals and its grading standards in the soils at both agricultural sites are shown in Table 9. The risk coefficients of Cd in all soil samples of crop rotation were heavy, while in at least half of the soil samples under crop rotation were heavy. Of the inspected metals, the range of Cd contamination posed the most dangerous potential ecological risk (Extremely strong), with an index of between 285 and 607.5 for soils under sugarcane monoculture. Whereas, the level of Cd contamination posed strong potential ecological risk (very strong), with a potential index of between 30 and 300 (Table 9). The potential risk coefficient (E_r^i) of Cr, Ni, and Pb soil samples was low under both agricultural systems. The order of the potential ecological risk associated with a particular metal of the studied heavy metals is Cd＞ Pb＞ Ni ＞ Cr.

The Hakanson potential ecological risk index (*RI*) evaluates comprehensively the potential ecological hazard and the degree of heavy metals contamination (Table 9). The potential ecological risk indices of heavy metals found at sugarcane soils ranged from 304.13 to 643.11, with an average value of 445.92, representing a strong ecological risk. The levels of *RI* for the topsoil layer of agricultural soils under sugarcane monoculture fell into strong ecological risk category, and those of crop rotation soils belonged to moderate category. Both values of I*geo* and *RI* of the surface soils in sugarcane areas were significantly higher than in crop rotation areas. Cadmium was the main pollutant in the 0–30 cm soil layer in both sugarcane monoculture and crop rotation soils with strong ecological risk category. Therefore, measures need to be introduced to comprehensively control the heavy metal contamination in sugarcane soils, especially for Cd and Pb, to strengthen the ecological restoration at the area of sugarcane belt in Upper Egypt. The Hakanson potential ecological risk index indicated that the overall pollution in the sugarcane monoculture soils at sugarcane belt of Upper Egypt was heavy.

Table 9. Environment risk assessment of sugarcane and crop rotation soils by the Hakanson potential ecological risk index (*RI*).

Land use	sugarcane monoculture					Contamination level	Crop rotation					Contamination level
	Cd	Cr	Ni	Pb	*RI*		Cd	Cr	Ni	Pb	*RI*	
1	285.00	1.98	5.90	11.25	304.13	strong	180.00	0.88	4.62	4.62	190.13	moderate
2	397.50	1.06	5.80	7.75	412.11	strong	300.00	0.62	4.30	6.50	311.42	strong
3	315.00	3.27	6.05	28.62	352.95	strong	292.50	0.68	2.22	9.50	304.91	strong
4	315.00	0.75	5.80	46.87	368.42	strong	97.50	0.36	1.75	28.37	127.98	low
5	450.00	2.93	6.00	52.75	511.68	strong	270.00	0.16	2.92	13.25	286.33	moderate
6	457.50	4.13	5.92	29.12	496.68	strong	217.50	0.56	3.45	13.87	235.38	moderate
7	315.00	4.73	6.37	30.37	356.48	strong	195.00	1.40	7.87	17.62	221.90	moderate
8	607.50	3.11	0.87	31.62	643.11	strong	60.00	0.57	0.32	14.87	75.77	low
9	420.00	2.80	15.57	27.87	466.25	strong	157.50	0.96	0.32	12.37	171.16	moderate
10	480.00	3.52	10.52	28.62	522.67	strong	142.50	0.92	1.95	13.87	159.25	moderate
11	427.50	3.03	6.47	54.75	491.76	strong	97.50	0.37	0.47	15.37	113.72	low
12	525.00	0.87	6.15	28.62	560.65	strong	142.50	0.56	0.57	15.75	159.38	moderate
13	307.50	3.77	9.30	29.12	349.7	strong	60.00	0.62	1.97	6.37	68.97	low
14	457.50	4.18	7.25	44.25	513.18	strong	112.50	0.93	1.05	4.12	118.61	low
15	322.50	1.60	6.17	8.75	339.02	strong	30.00	0.62	1.87	4.12	36.62	low
Descriptive Statistical Analysis												
Average	405.50	2.78	6.94	30.69	445.92		157.00	0.68	2.38	12.04	172.10	
Contamination degree	Extremely strong	low	low	low	strong		Very strong	low	low	low	moderate	
Max	607.50	4.73	15.57	54.75	643.11		300.00	1.4	7.87	28.37	311.42	
Min	285.00	0.75	0.87	7.75	304.13		30.00	0.16	0.32	4.12	36.62	
S.D mg/kg^{-1}	94.25	1.33	3.13	14.45	98.72		85.20	0.30	2.04	6.48	86.07	
C.V%	23.24	47.92	45.21	47.08	22.13		54.27	44.08	85.88	53.85	50.01	

The geo-accumulation index (I*geo*) and the Hakanson potential ecological risk index both yielded similar measures for the levels of soil heavy metal pollution at the investigated sites and thereby pollution of soils under long term irrigated sugarcane monoculture is confirmed. Both indices revealed similar levels of heavy metal pollution, indicating that the sugarcane soils are contaminated by the heavy metals to varying degrees compared to soils under crop rotation and the background values for the reference control soil. Significantly, the studied four heavy metals of Cd, Cr, Ni and Pb had light levels of contamination under sugarcane monoculture system compared to crop rotation system. The contamination order of heavy metals is, Cd> Pb> Ni> Cr.

Cadmium pollution was the main problem in the study area, with the overall soil Cd content indicating a strong degree of contamination. Therefore, effective control of Cd contamination is necessary under these farming systems. The risk coefficients of Cr, Ni and Pb at sites were all low, indicating that these heavy metals had a limited environmental impact at sugarcane monoculture sites. Cadmium Cd has the highest potential ecological risk index and poses the greatest damage to the sugarcane soils and crop rotation soils. Chromium Cr induced the least ecological hazard due to it has a relatively lower toxicity response factor. In contrast, Wang *et al*., (2018), by assessments of pollution levels of soils under sugarcane monoculture revealed that the highest environmental risk was arouse by Pb and moderate to strong Cd pollution was found.

CONCLUSION

The data characterize the first contamination survey of heavy metal contents in sugarcane fields of Upper Egypt and highpoint the significance of monitoring the concentrations of heavy metals in soils intensively farmed with sugarcane so as to protect the soil ecological functionalities and human health. The alluvial soils in Upper Egypt alongside the Nile River are intensively cultivated with sugarcane monoculture due to land shortage. Sugarcane monoculture is characterized by intensive irrigation using groundwater, intensive use of pesticides, extensive organic and inorganic fertilizers and gypsum due to the natural soil alkalinity. There were both environmental risks and human health consequences for peoples exposed to such pollutants of soils with heavy metals in the studied sugarcane belt area of Upper Egypt. Results indicating that sugarcane monoculture alluvial soils are contaminated by heavy metals to varying degrees compared to soils under crop rotation and the background values for the uncultivated soils. High accumulations of cadmium Cd, chromium Cr, nickel Ni and lead Pb should be taken into account in agricultural soils of sugarcane monoculture, as they are undegradable and have a high potential to enter the food chain causing reverse effects on soil microorganisms and soil environment. Heavy metal contamination in the alluvial soils sugarcane belt in Upper Egypt should be controlled so as to strengthen the ecological restoration and environmental protection at this site. Hence, quality of artificial and organic fertilizers should be controlled for lessening heavy metal contamination and guaranteeing yield quality, and huge consideration should be paid to decrease cumulation of Cd, Cr, Ni, Pb in soils by rational and balanced use of chemical and organic fertilizers for both land use systems, especially for the sugarcane monoculture.

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تأثير الاستخدامات المختلفة للأراضي على حالة العناصر الثقيلة والنشاط الميكروبي في التربة

محي الدين أحمد أبوشلبايه[1] ، محي الدين محمد عبدالعظيم[1]*، أحمد محمد منيسي[1] و محمود منصور عبدالمجيد[2]

[1] قسم الأراضي – كلية الزراعة – جامعة المنيا – مصر

[2] قسم المحاصيل – كلية الزراعة – جامعة المنيا – مصر

يجب أن تحصل التربة على أقصى قدر من الحماية لضمان الزراعة المستدامة وجودة الإنتاج الغذائي. تميل المعادن الثقيلة إلى التراكم في التربة بدلاً من التحلل وعند حد معين من محتواها ، تحدث عواقب سامة على الكائنات الحية. تم إجراء هذا البحث لحصر حالة تلوث الكادميوم والكروم والنيكل والرصاص والنشاط الميكروبي في التربة المتأثرة بالزراعة الأحادية لقصب السكر على المدى الطويل في صعيد مصر ، تراوحت الزيادة في التحلل المائي لثنائي الأسيتات فلورسين (FDA) من 86.25 إلى 201.25 مجم / كجم من التربة في حقول زراعة قصب السكر ، بينما أظهرت الزيادة تحت حقول الدورة الزراعية قيمًا أعلى معنوية وتراوحت هذه القيم من 207.25 إلى 266.67 مجم / كجم من التربة · في هذه الدراسة كانت الكتلة الحيوية الميكروبية في التربة والنشاط الإنزيمي عمومًا أعلى بشكل ملحوظ في ظل الدورة الزراعية مقارنة بالزراعة الأحادية لقصب السكر. تم العثور على أعلى المخاطر البيئية المحتملة في التربة تحت الزراعة الأحادية لقصب السكر المروى بالغمر على المدى الطويل. في ظل كل من نظام الزراعة الأحادية لقصب السكر ونظام الدورة الزراعية لوحظ أن الكادميوم هو صاحب أعلى درجة من التلوث على الرغم من أن الكادميوم يحتوي على أقل متوسط تركيز Cd 27.03 مجم / كجم (في حقول قصب السكر، و Cd (10.46 مجم) / كجم) تحت نظام الدورة الزراعية. في ضوء التأثيرات السامة المحتملة لهذه العناصر وهي الكادميوم (Cd) والكروميوم (Cr) والنيكل (Ni) والرصاص (Pb) ، على النظم الأيكولوجية والصحة العامة ، أصبح إدخال ممارسات زراعية جديدة في حقول زراعة قصب السكر الأحادية ضرورة لحماية البيئة وتحقيق الاستدامة المستقبلية في إنتاج قصب السكر في صعيد مصر.